Implementing a Solar Panel System at King Hamad University Hospital: A Pathway to Sustainability and Cost Efficiency

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Abstract: - Purpose: This paper analyses the functioning of a solar panel system at King Hamad University Hospital (KHUH), indicating its part in enhancing sustainability and cost-efficiency. Due to the increasing demand in renewable energy, this study illustrates how healthcare facilities can minimize operational costs using solar energy. Methodology: The study details the integration of solar panels into KHUH's infrastructure, importance their potential for energy generation. It encompasses a methodical investigation of the project's technical, economic, and environmental scope, aligning with the hospital's commitment to responsible resource management. *Findings*: The study reveals that KHUH's implementation of solar panels much reduces electricity payment, in this manner present substantial cost savings. It also enhances the hospital's energy safety and leads to an important reduction in greenhouse gas emissions, reflecting its commitment to environmental impacts.
Originality: This paper's originality lies in its determined inspection of solar panel integration in a hospital, underlining in cooperation economic and environmental profit. It contributes to the role of renewable energy in healthcare, showcasing KHUH's original role in sustainable and efficient resource management in the medical sector.

Key-Words: - Implementing, Solar Panel System, King Hamad University Hospital, Pathway, Sustainability, Cost Efficiency

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1 Introduction

King Hamad University Hospital (KHUH) was established by Royal Decree No. 31 of 2010, which affiliated it to the Bahrain Defense Force. It was officially opened by his majesty King Hamad Bin Isa AL Khalifa on 2/2/2012. KHUH is a university hospital primarily serving the Royal College of Surgeons of Ireland, Bahrain branch, which is located at its western border. KHUH has a capacity of 739 beds, in all services. (In- patients including isolation rooms: 348, Out-patient clinics: 242, other services: 149). With 1731 employees [1, 2]. The project started in 2003 as King Hamad General Hospital to help meet the increasing healthcare needs in Bahrain. KHUH now is a specialized hospital for the delivery of state of-the-art healthcare, teaching, and research, in addition to fulfilling the national agenda defined in Bahrain Vision 2030 [3, 4]. Due to their large building volume and their continuous operation, hospitals are considered to be among the most energy-intensive building units, with a highly negative impact on the environment [5, 6]. The constant human activity that takes place in these buildings and the numerous people who are working or moving into these structures make proper energy management a necessity. Furthermore, energy management in hospitals is an important factor since its mismanagement leads to an increase in operating costs, a negative environmental impact, and a decrease in competitiveness [7]. However, the medical devices used in intensive care units (ICU), surgery rooms, imaging units, and furnaces also require large amounts of energy for smooth functioning. Nevertheless, the largest energy consumption in hospital units comes from cooling, lighting, and hot water, which are usually covered by the cogeneration of electricity, gas, and oil and, in some cases, by photovoltaic solar panels [8–11]. Governments and hospital administrations are looking for economical energy solutions that will subtractive work in addressing the high prices that they pay to secure energy, in order to reduce operating costs [12, 15].

2 The Importance of Reducing Energy Consumption

The two main benefits of reducing energy consumption are the economic benefits and the environmental benefits. While a facility may wish to conduct an energy assessment for either or both of the reasons, getting funding to make improvements to the facility is typically easier when the goal of the assessment is to reduce energy costs [16-18]. If hospital staff is looking to reduce the costs associated with energy consumption, two main reasons why an assessment was not typically carried out previously are that the staff did not understand the total costs that the hospital was currently incurring or the staff did not understand the costs associated with making improvements [19]. One of the most important pieces of information that a researcher conducting an energy assessment can provide is a breakdown of the overall costs the hospital is incurring from energy use. Oftentimes, seeing what costs are associated with certain fixtures or practices can result in changes to the culture or policies at the hospital. Additionally, the hospital staff may not have had the time or expertise to research what options were available to lower the costs of energy consumption. Even though the hospital may have a sustainability committee, the employees that sit on that committee still have the primary responsibility of ensuring that the hospital is running smoothly and caring for patients. Their primary responsibility is not to improve on the situation of the hospital’s energy consumption [20-24].

Implementing strategies to reduce energy consumption in hospitals is not only a financial imperative but also a moral one, considering the healthcare sector's commitment to promoting health and well-being. By adopting the latest energy-efficient technologies, following best practices in energy management, and learning from successful case studies, hospitals can achieve significant reductions in energy use, resulting in cost savings and a lower environmental impact. As healthcare facilities continue to evolve, integrating sustainability into their core operations will be key to their long-term success and contribution to a healthier planet [25, 26].

3 Renewable Energy Potentials

Bahrain’s Vision 2030 outlines measures to protect the natural environment, reduce carbon emissions, minimize pollution, and promote sustainable energy. Bahrain is committed to designing energy efficiency policies and promoting renewable energy technologies that support Bahrain’s long-term climate action and environmental protection ambitions. Endorsed by Bahrain’s Cabinet and monitored by SEA, the National Energy Efficiency Action Plan (NEEAP) and the National Renewable Energy Action Plan (NREAP) set national energy efficiency and national renewable energy 2025 targets of 6 and 5 percent, respectively, with the NREAP target increasing to 10 percent by 2035[27].

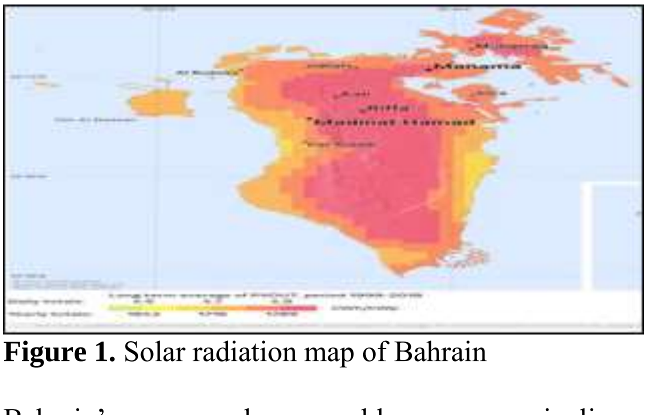

Figure 1. Solar radiation map of Bahrain

Bahrain’s proposed renewable energy pipeline consists of solar, wind, and waste to energy technologies, with plans to capture the majority of Bahrain’s renewable energy mix from solar power. Some of Bahrain’s key solar initiatives include: planning for a solar farm project on the Askar landfill, delivering 100 megawatts of renewable power; a 50-megawatt initiative to install solar panels on the roofs of hundreds of government-owned buildings, and the potential installation of "floating solar" technologies to be deployed for power generation in Bahrain's territorial waters in order to address the problem of land scarcity for larger solar farms. Figure1 shows the solar radiation map in kingdom of Bahrain. The average annual solar radiation available in Bahrain is around 2,600 kWh/m2 /year and the technical potential for electric generation using solar thermal technology is about 33 TWh per year. [28, 29].

Direct projects can supply as a litmus test for broader achievement. For example, a small-scale system at a society health center might offer expensive insights into the logistical, technological, and financial aspects of solar projects in healthcare settings. Such initiatives can cover the way for larger-scale implementations across Bahrain's hospitals and healthcare services. Furthermore, worldwide collaboration can play an important role in overcoming these challenges. Knowledge from worldwide best practices and leveraging international expertise can help Bahrain find the way to adopting solar energy solutions in healthcare, ensuring that these initiatives are together sustainable and cost-effective. [30-32]

4 Methodology

The methodologies for adapting a solar panel system at KHUH include a series of key steps intended at ensuring its successful implementation. First, a full implementation plan is developed, outlining the project step by step. Key project details are highlighted, including a design load of 4000 kW (DC), division into 14 areas each with 10,000 PV modules at 400 W each, the use of 54 inverters, and total area coverage of 20,000 square meters. Figure 2, depicting the Project Master Plan, and Figure 3, illustrating the installation process, complement the methodology

Figure 2. Project Master plan

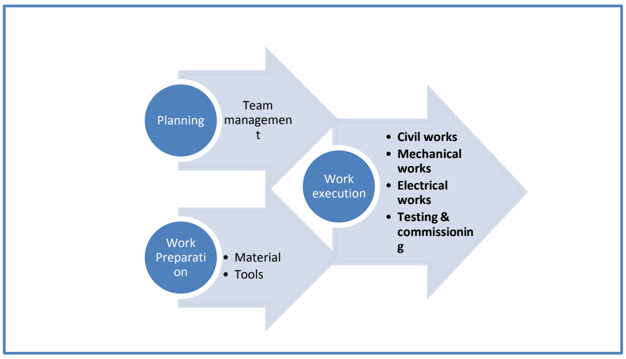

Figure 3. System installation process internal

This comprehensive approach facilitates a thorough assessment of feasibility, energy generation capacity, financial viability, and environmental benefits, ultimately guiding the successful installation and operation of the solar panel system, aligning with the hospital's commitment to sustainability and cost-efficiency. The provided figure 4, illustrates the setup of a solar panel system, showcasing its key components and their interconnected functionality. At its core, the system features solar panels, responsible for harnessing renewable solar energy. This generated DC power is efficiently managed through a DC distribution box, ensuring smooth flow into the system. The inverter plays a pivotal role in converting DC power into usable AC electricity for consumption and grid export, facilitated by the electrical control panel. The EWA bidirectional meter is integrated to monitor the energy exchange between the system and the external EWA grid, allowing for precise measurement and billing. Finally, the electrical control panel efficiently channels the converted energy to the electrical internal load, powering the facility while potentially exporting excess energy back to the grid, illustrating a comprehensive and sustainable energy ecosystem.

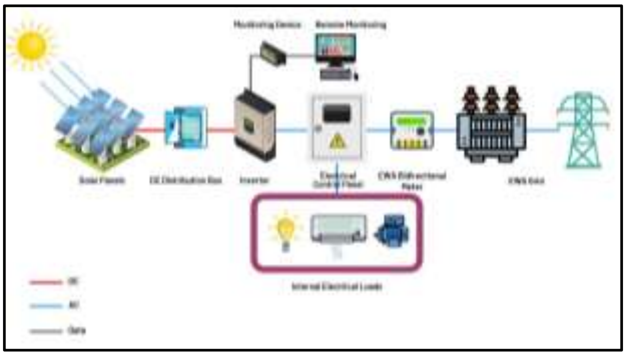

Figure 4. The setup of a solar panel system

4.1 Converter Selection and Specifications

In the implementation of the solar panel system at KHUH, a critical component was the selection of an appropriate converter. For the system, SUN2000-60KTL-M0 were chosen, a highly efficient and reliable converter for converting the variable direct current (DC) output of the photovoltaic (PV) cells into a grid-compatible alternating current (AC). This type was chosen because it met the specifications and scale of the solar system at our hospital.

4.2 Technical Capabilities

SUN2000-60KTL-M0 is a model of a specific one. String inverter that is manufactured by Huawei. Here are Some common specs for the SUN2000-:60KTL-M0:

- Power rating: The maximum amount of AC power that the inverter can provide to the grid
- Maximum DC voltage: The maximum DC voltage that the SUN2000-60KTL-M0 can operate at is normally around 1100 volts.
- Efficiency: It is a measure of how the inverter does its job of converting DC power into AC power. Typically, the SUN2000-60KTL-M0 is known to have a high efficiency above 98% under given conditions of operation.
- Input voltage range: The inverter allows different configurations of solar panels and string layouts
- Monitoring and communication: The SUN2000-60KTL-M0 has advanced monitoring and communication features.
- Protection features: is fitted with a series of protection measures to ensure the safe and reliable operation of the equipment.

4.3 Justification of Choice

The hospital selected the SUN2000-60KTL-M0 due to its specific requirements. The ability to switch the required energy loads, combined with its efficiency, safety character, and ease of incorporation, made it the perfect choice for our solar energy system. The system's overall effectiveness and sustainability align with our goal of reducing energy expenses and mitigating environmental impacts.

5 Results & Discussion

5.1 Energy Output Calculations

In our study, we have taken into consideration the calculation of the energy output from the photovoltaic system installed at KHUH. The following formula can be used:

ENERGY OUTPUT (kWh/month) = SOLAR ARRAY AREA (m2) x CONVERSION EFFICIENCY x SOLAR RADIATION FOR THE MONTH (kWh/m2/day)

Factors affecting the daily solar power calculations:

- **Tracking system:** This system effectively adjusts the position of the solar panels to track the sun's movement throughout the day. The optimization of the panel orientation helps in increasing the daily power production when compared to the fixed-tilt systems. So, it is important for any solar panel system to have a functional tracking system.
- **Inverter efficiency:** Solar inverters convert the direct current or DC produced by the solar cells into working alternating current or AC for use in residential or commercial places. So, inverter efficiency plays a crucial role in the overall system performance.
- **Temperature effects:** The temperature coefficient defines the impact of temperature on solar panels. It refers to the decrease in solar panel efficiency due to the temperature rise.
- **Shading:** The impact of the shading from nearby objects like trees, buildings, or other structures to solar panels affects its kWh production.
- **System orientation:** The orientation and tilt angle of the solar panels impact the solar energy output.
- **Panel efficiency:** The efficiency of the solar panels affects the total **solar panel energy production**. Modern solar panels have an efficiency of around 15% to 22%.
- **Solar irradiance:** It is the term referring to the total amount of sunlight energy received per unit area at a given time and location.

5.2 Environmental Impact Analysis

Our study of the environmental impact, mainly in terms of CO_2 emissions reduction, was conducted using the following formula:

CO_2 (kg) = kWh produced x CO_2 Factor (g/kWh).

Each kWh of electricity can be generated using fossil fuel, which generates CO_2 emissions. The number shown is the quantity of CO_2 emissions that would have been generated by an equivalent fossil fuel system. This number depends on the systems' location; the emissions level in each country.

Figure 5, provides a snapshot of a solar system's performance, showing its current electricity output (active power), daily energy production (E-daily), total energy generated to date (E-total), and the amount of CO_2 emissions it has reduced. It offers a quick overview of the system's efficiency and environmental benefits.

Figure 5. A snapshot of a solar system's performance

In the provided dataset, there are three figures (6, 7, 8), corresponding to the years 2021, 2022, and 2023. Each figure is structured to display a month-by-month analysis of two critical aspects of a solar system's performance:

Yield (kWh): These values signify the amount of electricity generated by the solar system on a monthly basis throughout the respective year. This data offers insights into the system's productivity and its ability to capture solar energy effectively.

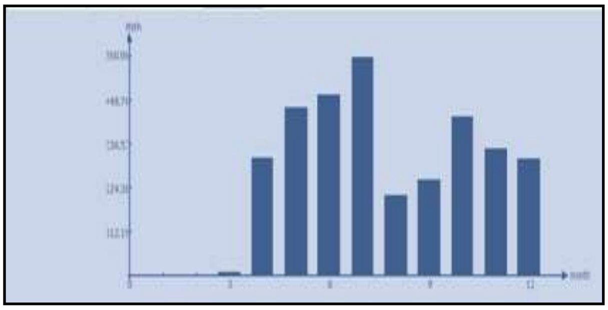

Figure 6. Yearly Energy Production 2021

Reduction CO2 Emission (kg): This leads to efficit to the environmental impact of the solar system. the volume of carbon dioxide emissions that have been generated or prevented by the utilization of clean solar energy, as opposed to energy derived from fossil fuels. These figures underscore the solar system's role in reducing greenhouse gas

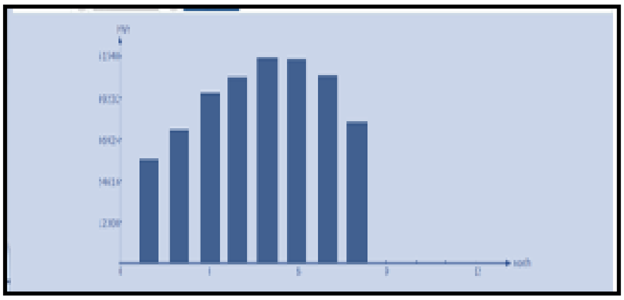

Figure 7. Yearly Energy Production 2022

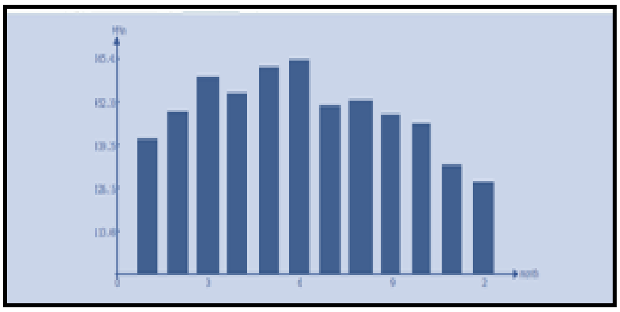

Figure 8. Yearly Energy Production 2023

Table 1 illustrates the yearly production of energy in 2021, the solar panel system generates 3,264,381.62 KWh, per year of energy, compared to 2,154,491.87 kg of CO2 emissions. It's an important contribution to cooperation in environmental sustainability and cost efficiency.

Table .1. Yearly Energy Production 2021

Time	Yield(KWh)	ReducedCO2 Emission(kg)	Revenue (S)
2021-01	0.00	0.00	0.0
2021-02	0.00	0.00	0.0
2021-03	9238.38	6097.33	267.9
2021-04	304443.72	200932.86	8828.9
2021-05	433390.04	286037.43	12568.3
2021-06	464348.76	306470.18	13466.1
2021-07	559956.17	369571.07	16238.7
2021-08	208574.43	137659.12	6048.7
2021-09	207499.63	163349.76	7177.5
2021-10	410025.52	270616.84	11890.7
2021-11	326347.86	215389.59	9464.1
2021-12	300557.11	198367.69	8716.2
Total	3264381.62	2154491.87	94667.1

Table 2 illustrate the yearly production of energy in 2022, the solar panel system generates 5,153,121.23 KWh, per year of energy, compare to 3,401,060.01 kg of CO2 emissions. It’s important contribution to in cooperation environmental sustainability and cost efficiency.

Table .2. Yearly Energy Production 2022

Time	Yield(KWh)	ReducedCO2 Emission(kg)	Revenue (S)
2022-01	35748.46	235935.78	10366.9
2022-02	429287.83	283329.97	12449.3
2022-03	520171.29	343313.05	15085.0
2022-04	477163.86	314928.15	13837.0
2022-05	546102.85	360427.88	15837.0
2022-06	564412.29	372512.11	16368.0
2022-07	446289.90	294551.33	12942.4
2022-08	458908.27	302879.46	13308.3
2022-09	420639.93	277622.35	12198.6
2022-10	399236.50	263496.09	11577.9
2022-11	288623.32	190491.39	8370.1
2022-12	244806.73	161572.44	7099.4
Total	**5153121.23**	**3401060.01**	**149440.5**

Table 3 illustrates the yearly production of energy in 2022, the solar panel system generates 3,990,242.99 kWh, per year of energy, compare to 2,633,560.37 kg of CO2 emissions. It's an important contribution to cooperation in environmental sustainability and cost efficiency.

Table .3 Yearly Energy Production 2023

Time	Yield(KWh)	ReducedCO2 Emission(kg)	Revenue(S)
2023-01	313555.17	206946.41	9093.1
2023-02	399707.99	263807.27	11591.5
2023-03	510775.74	337111.99	14812.5
2023-04	555318.65	366510.31	16104.2
2023-05	614401.53	405505.01	17817.6
2023-06	610447.99	402895.67	17703.0
2023-07	561983.10	370908.85	16297.5
2023-08	424052.82	279874.86	12297.5
2023-09	0.00		
2023-10	0.00		
2023-11	0.00		
2023-12	0.00		
Total	**3990242.99**	**2633560.37**	**115717.0**

As shown in Figure 9 the relation between electricity bill and load, while a new equipment installation or new services opened, its lead to increasing the electricity usage therefore increasing the electricity bills.
However, integrating a solar system into the existing infrastructure can offset this impact. Solar panels generate renewable energy, reducing reliance on grid electricity and subsequently lowering electricity bills. This relation between new loads and solar energy showcases the possible for cost savings and improved Sustainability, making it a practical choice for both residential and commercial energy management.

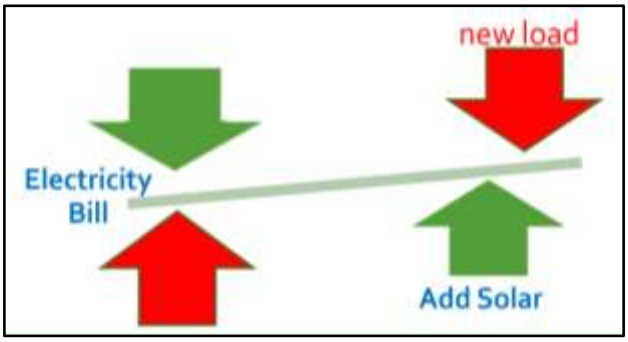

Figure 9. The relation between electricity bill and load

Regular cleaning of solar panels is essential to continue their best performance and efficiency. A study has exposed that after just 55 days of dust increase; the power output of mono-crystalline silicon (m-Si) solar panels can decline by as much as 40% [23]. This major drop underscores the harmful impact of dust and remains on solar panel efficiency. Accumulated dust on the panels' surface hinders sunshine from efficiently reaching the photovoltaic cells, leading to decreased energy production. Therefore, to guarantee efficient sunshine harnessing and maximize electricity generation, KHUH has implemented a monthly cleaning schedule for its solar panels.

In order for our methodologies to insure requirements of KHUH, we are looking for factors such as the hospital's incessant process and serious power needs. This was fundamental for a practical assessment of the system's impact. For example, the 24/7 operation model of the hospital meant that our energy output calculations had to consider the nonstop use of essential medical equipment. This detail came up to ensure that our analysis exactly reflected the hospital's exceptional energy usage profile, in this manner enabling us to evaluate the true value of the solar installation in gathering the hospital's energy consumption and sustainability objectives.

The expected outcomes of implementing a solar panel system at KHUH are involved and transformative, moving upon a range of aspects of sustainability, efficiency, and environmental stewardship. The predictable outcomes include:

- **Clean Energy Generation**: The solar panel system is projected to generate a substantial amount of clean, renewable energy. This will not only decrease the hospital's dependence on non-renewable energy sources however also much lower its carbon emission.
- **Cost Savings**: Utilizing solar energy for a portion of the hospital's electricity needs could lead to

considerable cost savings. By implementing the new method, we expect a reduction in monthly electricity bills by approximately [10%], resulting in substantial long-term financial benefits.

- **Financial Viability**: The cost-benefit investigation of the solar panel structure showing a good return on investment. The result highlights the cost-effective return of solar energy, showing that the primary capital spending will be counterbalanced by long-term savings.
- **Environmental Benefits**: Environmental impact estimation predicts a remarkable decrease in greenhouse gas emissions and air pollutants. By implementing solar energy, the hospital will make efforts in environmental management and sustainability.
- **Community Engagement**: This study serves as a way for sustainable practices, potentially moving society members, other hospitals, and businesses to look at renewable energy solutions, by this means encouraging a culture of sustainability.
- **Educational Opportunity**: The solar system offers knowledge in relation to renewable energy technologies. It provides a chance for teamwork with educational institutions in research, workshops, and awareness campaigns.
- **Operational Resilience**: Incorporating renewable energy enhances the hospital's flexibility aligned with energy cost fluctuations. This is particularly fundamental for a healthcare facility, where a constant power supply is very important for patient care.
- **Long-Term Impact**: The achievement of this development could place an example for other healthcare facilities, representing the possibility and flexibility of renewable energy in different contexts.

6. Conclusion

In conclusion, the employment of a solar panel system at KHUH characterizes a significant phase to sustainability and cost efficiency in the hospital. The complete method accepted, connecting viability studies, energy audits, and cost-benefit analyses, has systematically evaluated the project's potential, encouraging its viability and long-term benefits

A promising way for improving the system's efficiency and dependability lies in the engagement of Artificial Intelligence (AI) for the initial discovery of faults and analytical maintenance. By applying advanced (AI) systems accomplished of monitoring the system's show in real-time, this methodology aims to classify differences and forecast possible failures earlier they happen. Such predictive competences can extremely decrease maintenance costs, minimize interruption, and significantly spread the lifetime of the solar panel system. The results, as complete in the study, potential a future of clean energy generation, reduced reliance on conventional energy sources, and a noticeable reduction in carbon emissions. Figures 2, 3, 4, and 5 efficiently demonstrate the solar panel system's performance, showcasing the daily energy production, monthly differences, and year-long efficiency. These graphical tools not only support in monitoring the project's improvement but also highlight the flexibility of the system to various operating needs, supporting the sustainability at KHUH.

Economically, the project has shown significant cost reduction savings improving the hospital's financial efficiency. The perceptible reduction in environmental influence dovetails with KHUH's philosophy of responsible resource management and supports global climate change extenuation efforts.
The annual energy production reports, as shown in Figures 6, 7, and 8, highlight the reliable energy generation by the solar system and its possible long-term positive effect. This solar panel system implementation at KHUH not only helps as an efficient energy solution but also stands as a model for other institutions considering a move to sustainable practices.

By marrying sustainability with cost efficiency and environmental stewardship, KHUH's initiative emerges as a guiding light for healthcare facilities globally, showcasing the harmonious blend of operational excellence and ecological responsibility.

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Authors' contributions

Ahmed Albinali, Mohamed Alseddiqi and Anwar AL-Mofleh: provided the conception and design of the study, acquisition of data, analysis and interpretation of data, drafting the article, revised it critically for important intellectual content, and final approval of the version to be submitted

Osama Najam: supplied the acquisition of data, drafting of paper;

Leena Albalooshi: supplied the design of study, analysis and interpretation; supplied the acquisition of data.
Budoor Almannaei: was responsible for the article critically for important intellectual content; and Ahmad Bataineh: provided the revised the article critically for important intellectual content and gave final approval of the version to be submitted.

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